



Figure 4: Effect of query expansion by adding nearby terms in W_p (1) in traditional language models (Model 1 [4] with Jelinek-Mercer smoothing) for W3C, CERC and TU benchmarks.

APPENDIX

The derivative of (3) w.r.t. bias term b_c equals

$$\frac{\partial L(W_p, W_c, b_c)}{\partial b_c} = -\frac{1}{m} \left(\sum_{i=1}^m \frac{|d_{\max}|}{|d^{(i)}|} \sum_{j=1}^{|C|} P(c_j | d^{(i)}) \frac{\partial \log(P(c_j | w_1^{(i)}, \dots, w_n^{(i)}))}{\partial b_c} \right)$$

and w.r.t. an arbitrary matrix parameter θ (W_p or W_c):

$$\frac{\partial L(W_p, W_c, b_c)}{\partial \theta} = -\frac{1}{m} \left(\sum_{i=1}^m \frac{|d_{\max}|}{|d^{(i)}|} \sum_{j=1}^{|C|} P(c_j | d^{(i)}) \frac{\partial \log(P(c_j | w_1^{(i)}, \dots, w_n^{(i)}))}{\partial \theta} \right) + \frac{\lambda}{m} \sum_{i,j} \theta_{i,j}.$$

Further differentiation for parameter θ (W_p , W_c or b_c):

$$\begin{aligned} \frac{\partial \log(P(c_j | w_1, \dots, w_n))}{\partial \theta} &= \frac{1}{P(c_j | w_1, \dots, w_n)} \frac{\partial P(c_j | w_1, \dots, w_n)}{\partial \theta} \\ &= \frac{\frac{\partial \tilde{P}(c_j | w_1, \dots, w_n)}{\partial \theta} Z_2 - \tilde{P}(c_j | w_1, \dots, w_n) \frac{\partial Z_2}{\partial \theta}}{Z_2^2} \\ \frac{\partial Z_2}{\partial \theta} &= \sum_k \frac{\partial \tilde{P}(c_k | w_1, \dots, w_n)}{\partial \theta} \\ \frac{\partial \tilde{P}(c_j | w_1, \dots, w_n)}{\partial \theta} &= \sum_k \frac{\partial P(c_j | w_k)}{\partial \theta} \prod_{i \neq k} P(c_j | w_i) \end{aligned}$$

For a given candidate c_j and word w_i , following (1) we have

$$\begin{aligned} P(c_j | w_i) &= \frac{\tilde{P}(c_j | w_i)}{Z_1} \\ &= \frac{\exp((\sum_{k=1}^e W_{c_j,k} W_{p_{k,i}}) + b_{c_j})}{\sum_{l=1}^{|C|} \exp((\sum_{k=1}^e W_{c_l,k} W_{p_{k,i}}) + b_{c_l})} \end{aligned}$$

and consequently, with $\mathbf{W}_{p_i}^\top$ denoting the i -th column of matrix W_p ,

$$\begin{aligned} \frac{\partial P(c_j | w_i)}{\partial \mathbf{W}_{c_j}} &= \frac{(Z_1 - \tilde{P}(c_j | w_i)) \tilde{P}(c_j | w_i) \mathbf{W}_{p_i}^\top}{Z_1^2} \\ \frac{\partial P(c_j | w_i)}{\partial b_{c_j}} &= \frac{(Z_1 - \tilde{P}(c_j | w_i)) \tilde{P}(c_j | w_i)}{Z_1^2} \quad (7) \\ \frac{\partial P(c_j | w_i)}{\partial \mathbf{W}_{p_i}^\top} &= \frac{(\mathbf{W}_{c_j} - \sum_{l=1}^{|C|} \mathbf{W}_{c_l}) \tilde{P}(c_j | w_i)}{Z_1} \end{aligned}$$

As can be seen in (7), the distributed representations of candidates c_j at time $t+1$ are updated using the representation of words w_i at time t and vice versa.

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